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Comparison of Polyimide to Silicon Nitride Membranes for Robust Thermal Flow Sensors

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Summary:

This work compares thin and robust polyimide membranes for thermal flow sensors to flow sensors based on silicon nitride membranes. Due to the low thermal conductivity of polyimide, the sensitivity measurements are showing only a small reduction in sensitivity of less than 20% when a polyimide membrane with a ten times higher thickness compared to a silicon nitride membrane is used. At the same time the polyimide membrane can withstand a 50% higher pressure difference which leads to a significant improvement of the robustness.

Keywords: thermal flow sensors, polyimide, silicon nitride, membranes, microfabrication

Introduction

Microfabricated thermal flow sensors are used in a wide range of applications like aerospace [1]. One commonly used method to measure the flow is the calorimetric principle. Here, the heat distribution generated by a heating wire is measured by thermistors, thermopiles or diodes [1]-[3]. The domains including the sensitive elements are often thermally insulated to reach a highly sensitive system with less heat losses [2], [3]. Thermal insulation can be achieved using a silicon nitride membrane by removal of the bulk material [3]. There is also research ongoing in using polyimide as a substrate material for thermal insulated calorimetric flow sensors [4]. Polyimide can be used due to its low thermal conductivity of 0.28 W/mK and its excellent robustness compared to silicon nitride membranes [5].

Although many approaches to polyimide-based flow sensors have already been investigated, a direct comparison between polyimide and silicon nitride membrane-based flow sensors has not been published until now to the authors' knowledge. Therefore, we compare the performance of flow sensors with a thinner polyimide membrane compared to the state of the art to one with a silicon nitride membrane.

Materials and Methods

To see the influence of the use of polyimide membranes on thermal flow sensors compared to conventional silicon nitride membranes the same pattern is used for the sensitive elements in both variations. The design consists of a heater in the center of the chip and symmetric thermistors on the up- and downstream side with a distance of 1 mm to the heater. Both, heater and thermistors, are placed on the membrane with a diameter of 4 mm. For electrical connection, bondpads for wire bonding are designed on the silicon bulk material.

The flow sensors are fabricated on silicon with a 1 µm thick layer of thermal silicon oxide for electrical insulation. Polyimide (U-Varnish-S, UBE Europe GmbH, Germany) is spin-coated on the wafer with a thickness of 4.7 µm, while silicon nitride is deposited with LPCVD method with a thickness of 500 nm. The heater and the thermistors are made of platinum with a thickness of 200 nm. To realize a membrane, the bulk material under the sensitive elements is removed by DRIE using SF6 and C4F8.

Experiments

Flow measurements are done in a wind tunnel with flow velocities up to 2.6 m/s. The heater is powered to 150 mW. Both sensors show no drift over 100 test cycles under thermal load.

To maintain the usability in fast reacting applications, the time response of both types of sensors is measured. For that, a flow is applied above the sensor and the change in resistance is plotted. In Fig. 1 such a plot is shown for a sensor with a silicon nitride membrane. The time response is calculated as the time difference between 10% and 90% of the mean value with/without a present flow. The flow sensors with silicon nitride membranes are showing a faster response time

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of t_{SiN} = 16 ms compared to the t_{PI} = 28 ms of the ones with polyimide membranes.

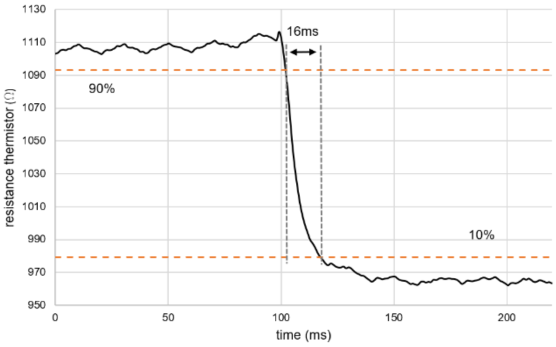

Fig. 1. Time response for the flow sensors with silicon nitride membranes.

Due to the different heat transfer in the membranes, the total change in resistance is limited by the materials used. Therefore, the difference in resistance between the thermistors up- and downstream is shown in Fig. 2 for different flow velocities. The output signal is up to 20% higher for the sensors with silicon nitride membranes compared to those with polyimide membranes.

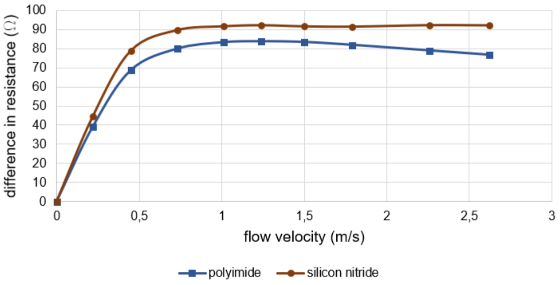

Fig. 2. Flow measurements with polyimide and silicon nitride membrane-based flow sensors.

A pressure difference is applied between both sides of the membrane to compare its robustness. In Tab. 1 the maximum pressure differences until a failure occurs are given. The polyimide membrane can withstand much higher pressure differences due to its high elasticity. Nevertheless, the heater and thermistors break at the same pressure since the strain is also increased due to the membrane deflection.

Tab. 1: The maximum pressure difference until the heater and thermistors or the membrane is damaged.

Membrane material	Heater and thermistors	Membrane
Silicon nitride	300 kPa	300 kPa
Polyimide	300 kPa	450 kPa

Conclusion and Outlook

This paper shows, that the time response is less than a factor 2 higher using a polyimide membrane, even though the thickness is approx. 10 times higher. The reason for that is the different heat capacity. Due to the lower thermal conductivity of polyimide, the difference in sensitivity is much lower. The flow sensors based on silicon nitride membranes are only up to 20% better. The major advantage of using flow sensors with polyimide membranes is the opportunity of using higher thicknesses than silicon nitride membranes without a significant reduction of sensitivity and time response. This leads to a more robust membrane, which can be used in e.g. aircraft applications for a stall detection sensor. Unfortunately, the sensing elements on the membrane cannot withstand the same pressure as the membrane itself. This could be solved by supporting the membrane structure with highly thermal insulating materials like aerogels. Also, the design needs to be optimized to increase the sensors range.

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References

[1] L. Ribeiro, O. Saotome, R. d’Amore, R. de Oliveira Hansen, High-speed and high-temperature calorimetric solid-state thermal mass flow sensor for aerospace application: A sensitivity analysis, *Sensors*, vol. 22, no. 9: 3484 (2022); doi: 10.3390/s22093484

[2] B. W. van Oudheusden, A. W. van Herwaarden, High-sensitivity 2-D flow sensor with an etched thermal isolation structure, *Sensors and Actuators A*, vol. 22, pp. 425 – 430 (1990); doi: 10.1016/0924-4247(89)80007-X

[3] R. Buchner, M. Maiwald, C. Sosna, T. Schary, W. Benecke, W. Lang, Miniaturised thermal flow sensors for rough environments*, In Proceedings of the 19th IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2006)*, pp. 582–585 (2006); doi: 10.1109/MEMSYS.2006.1627866

[4] T. Tsukada, R. Takigawa, Y. Hasegawa, M. S. Al Farisi, M. Shikada, Sensitivity enhancement of tube-integrated MEMS flow sensor using flexible copper on polyimide substrate, *Micromachines*, vol. 14, no. 1: 42 (2022); doi: 10.3390/mi14010042

[5] D. Briand, S. Colin, A. Gangadharaiah, E. Vela, P. Dubois, L. Thiery, N. F. de Rooij, Micro-hotplates on polyimide for sensors and actuators, *Sensors and Actuators A*, vol. 132, no. 1, pp. 317 – 324 (2006); doi: 10.1016/j.sna.2006.06.003